AFCRL-62-51

Nuclear Magnetic Resonance in Flames

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Abstract

In the thermal generation of nuclear magnetic resonance phenomena, such as is found in flames or hot exhausts, energy is lost during the transition from a higher- to a lower-energy nuclear magnetic quantum state. The interaction that takes place is explained in simple theoretical terms, and the effects of resonance broadening by spin-spin interaction and an inhomogeneous magnetic field are considered. The amount of energy lost during the cooling of a hot jet exhaust was calculated using the environmental magnetic field of the earth. On the assumption that the energy was radiated by means of electromagnetic waves, attempts were made to detect this energy loss.

NUCLEAR MAGNETIC RESONANCE IN FLAMES

Introduction

The phenomenon of nuclear magnetic resonance is probably best recognized in the fields of organic chemistry and nuclear physics. In the years following its discovery by Purcell and Bloch in 1946, the phenomenon has been applied in the chemical analysis of solids, liquids, and gases. Comparatively little consideration, however, has been given to the thermal generation of the resonance which should take place as a gas undergoes a rapid change in temperature. Any rapid change in temperature, whether it is an increase or a decrease, should induce resonance just as immersion of the medium in an oscillatory magnetic field induces resonance.

A simple explanation of nuclear magnetic resonance will provide a necessary background, and the theory will be expanded to apply to some medium undergoing a rapid decrease in temperature. With this background, the amount of energy transfer possible for several commercial jet engines using JP-4 propellant can be determined quantitatively.

Attempts were made to detect any electromagnetic radiation produced during the cooling of the hot jet exhaust gas, and the method and results are described in detail. A simple approach to the thermal generation of nuclear magnetic resonance is presented, and the problems encountered in practical application are discussed.

1. Theoretical Aspects

The property of importance in nuclear magnetic resonance is the nuclear spin I, or the circulation of the nuclear charge. Such charge circulation generates a magnetic field; hence, the nuclear magnetic moment vector μ arises.

The nuclear magnetic moment vectors are quantized, or can take on only certain specified average values. Suppose, for example, that the nuclear spin I equals 1/2. ($I = 1/2$ will be used throughout.) The two possible orientations of the magnetic moment μ when it is immersed in a magnetic field H_o are shown in Fig. 1. The two possible quantum states are $m = +1/2$ and $m = -1/2$, where $-I \leq m \leq I$.

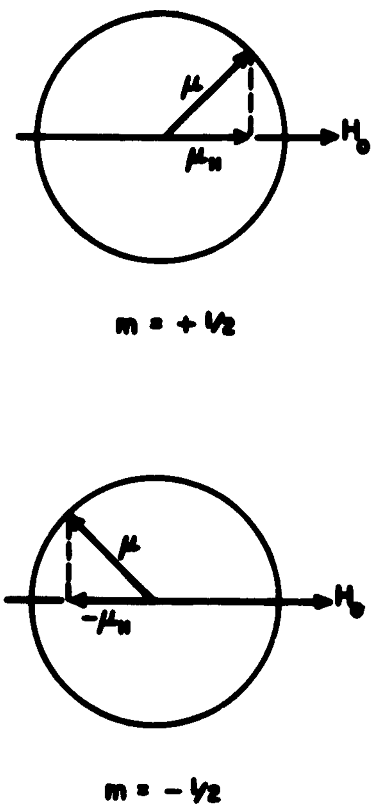

Figure 1. Two Possible Orientations of The Magnetic Moment μ When it is Immersed In a Magnetic Field

In the absence of a magnetic field, there is no particular preference for one state over the other, but in the case of an impressed magnetic field, the +1/2 state becomes the more favorable. This is simply shown by likening the magnetic moment vector to a compass needle. Orientation in the same direction as the impressed field, $m = +1/2$, corresponds to a normal compass needle orientation. Orientation in the opposite direction, $m = -1/2$, corresponds to the compass needle rotated 180°. The latter state requires work to be expended; thus the -1/2 state is the more energetic, hence the less favorable, state for occupation. If it were not for thermal agitation, the tendency to assume the more favorable +1/2 state would be unopposed.

If the population of the lower energy state is to be opposed by thermal agitation, there must be some mechanism for the transfer or coupling of energy from the surrounding medium (the lattice) into the lower energy spin quantum state. This mechanism is provided through the precession of the magnetic moment about the steady impressed magnetic field. If there is to be a transfer of energy, an oscillatory magnetic field of the same phase and frequency as that of precession must be impressed upon the medium. This condition produces a magnetic torque which tends to 'flip' or rotate the magnetic moment vector into the higher energy orientation, as in the case for a simple compass. Thus, energy is absorbed from the source that produces the oscillatory magnetic field.

To find the population distribution of energy states under the condition of thermal equilibrium for the spin temperature and the temperature of the lattice, the Boltzmann distribution law is applied with the nuclear magnetic moment μ, the steady magnetic field strength H_o, and the absolute temperature T:

$$N_m = \frac{N_o}{2I + 1} e^{-\frac{\epsilon_m}{kT}}$$

where N_m is the number of nuclei in the given m state, N_o is the total number of nuclei, ϵ_m is the energy associated with the given m state, and k is Boltzmann's constant.

$$\epsilon_m = -\mu_H H_o,$$

where μ_H is now written

$$\mu_H = \gamma_I m \hbar .$$

The nuclear gyromagnetic ratio is γ_I and $\hbar$ is Planck's constant.

$$\epsilon_{+1/2} = -\frac{\gamma_I \hbar H_o}{2} ; \qquad \epsilon_{-1/2} = \frac{\gamma_I \hbar H_o}{2} .$$

Then

$$N_{+1/2} = \frac{N_o}{2} e^{\frac{\gamma_I \hbar H_o}{2\,kT}} \; ; \qquad N_{-1/2} = \frac{N_o}{2} e^{\frac{-\gamma_I \hbar H_o}{2kT}} .$$

In the case of $N_{+1/2}$ at two different temperatures, say, along a flame from a higher to a lower temperature ($T_1 > T_2$):

For T_1

$$(N_{+1/2})\,T_1 = \frac{N_o}{2} e^{\frac{\gamma_I \hbar H_o}{2kT_1}}$$

For T_2

$$(N_{+1/2})\,T_2 = \frac{N_o}{2} e^{\frac{\gamma_I \hbar H_o}{2kT_2}}$$

$$(N_{+1/2})\,T_1 < (N_{+1/2})\,T_2 .$$

Thus for a change of temperature as described here, the number of nuclei in the +1/2 state is increased. Correspondingly, energy must be lost to the surroundings because there has been a decay, as it were, from the -1/2 to the +1/2 state. The number of nuclei that have experienced this decay is indicated by the increased population of the lower energy state.

$$\Delta N = (N_{+1/2})\,T_2 - (N_{+1/2})\,T_1 = \frac{N_o}{2}\left(e^{\frac{\gamma_I \hbar H_o}{2\,kT_2}} - e^{\frac{\gamma_I \hbar H_o}{2\,kT_1}}\right).$$

Expanding exponentially,

$$\Delta N = \left(\frac{N_o}{2}\right)\left(1 + \frac{\gamma_I \hbar H_o}{2\,k\,T_2} - 1 - \frac{\gamma_I \hbar H_o}{2\,k\,T_1}\right)$$

$$= \left(\frac{N_o}{2}\right)\left(\frac{\gamma_I \hbar H_o}{2\,k}\right)\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$= \left(\frac{N_o}{4}\right)\left(\frac{\gamma_I \hbar H_o}{k}\right)\left(\frac{T_1 - T_2}{T_1\;T_2}\right) = \frac{N_o}{4}\;\frac{\gamma_I \hbar H_o}{kT_1T_2}\;\Delta T;$$

$$dN = \left(\frac{N_o}{4}\right)\left(\frac{\gamma_I \hbar H_o}{k\,T_1T_2}\right) dT.$$

The rate of energy loss is proportional to

$$\frac{dN}{dt} = \left(\frac{N_o}{4}\right)\left(\frac{\gamma_I \hbar H_o}{kT_1T_2}\right)\frac{dT}{dt};$$

$$dT = \frac{\partial T}{\partial x}\,dx + \frac{\partial T}{\partial y}\,dy + \frac{\partial T}{dz}\,dz + \frac{\partial T}{\partial t}\,dt.$$

In the steady state $\frac{\partial T}{\partial t} = 0$. Then

$$\frac{dT}{dt} = \frac{\partial T}{\partial x} v_x + \frac{\partial T}{\partial y} v_y + \frac{\partial T}{\partial z} v_z$$

$$= \vec{v} \cdot \nabla T.$$

$$\frac{dN}{dt} = \left(\frac{N_o}{4}\right)\left(\frac{\gamma_I \hbar H_o}{k T_1 T_2}\right) \vec{v} \cdot \nabla T.$$

In the case of a flame, it is necessary to know the velocity components and temperature gradients, along with H_o and N_o, to determine the amount of energy loss.

In the case of an exhaust, such as a jet engine exhaust, and considering only one-dimensional (axial) flow:

$$\frac{dN}{dt} = \left(\frac{N_o}{4}\right) \frac{\gamma_I \hbar H_o}{kT_E T_A} \bar{v}_x \frac{dT}{dx},$$

where T_E and T_A are the exit and ambient temperatures respectively, and $\bar{v}_x$ is the average velocity. Three specific cases of interest are enumerated in Appendix A. Figure 2 shows the relationship between power loss in watts to the temperature gradient for these three cases.

Various authors (including this one) have assumed that the power lost is immediately radiated to the lattice by means of electromagnetic radiation of the proper frequency. This energy may simply be returned to the lattice by the reverse of the coupling mechanism discussed earlier. The energy lost would then be realized as a heating of the lattice.

The preceding discussion was concerned with a simple approach to a very complex interaction. There are many other factors that could have grave consequences so far as the production, loss, and detection of magnetic resonance energy in flames are concerned.

The foremost factor is, of course, that the magnetic spin energy loss may be simply realized in the form of thermal energy without any subsequent electromagnetic radiation at all. The extent of the spin-lattice interaction must therefore be considered more in detail. The spin is the spin of the nuclei and the lattice is the framework or material, whether gas, liquid, or solid, within which the nuclei are found. Present opinion is that while this interaction is so

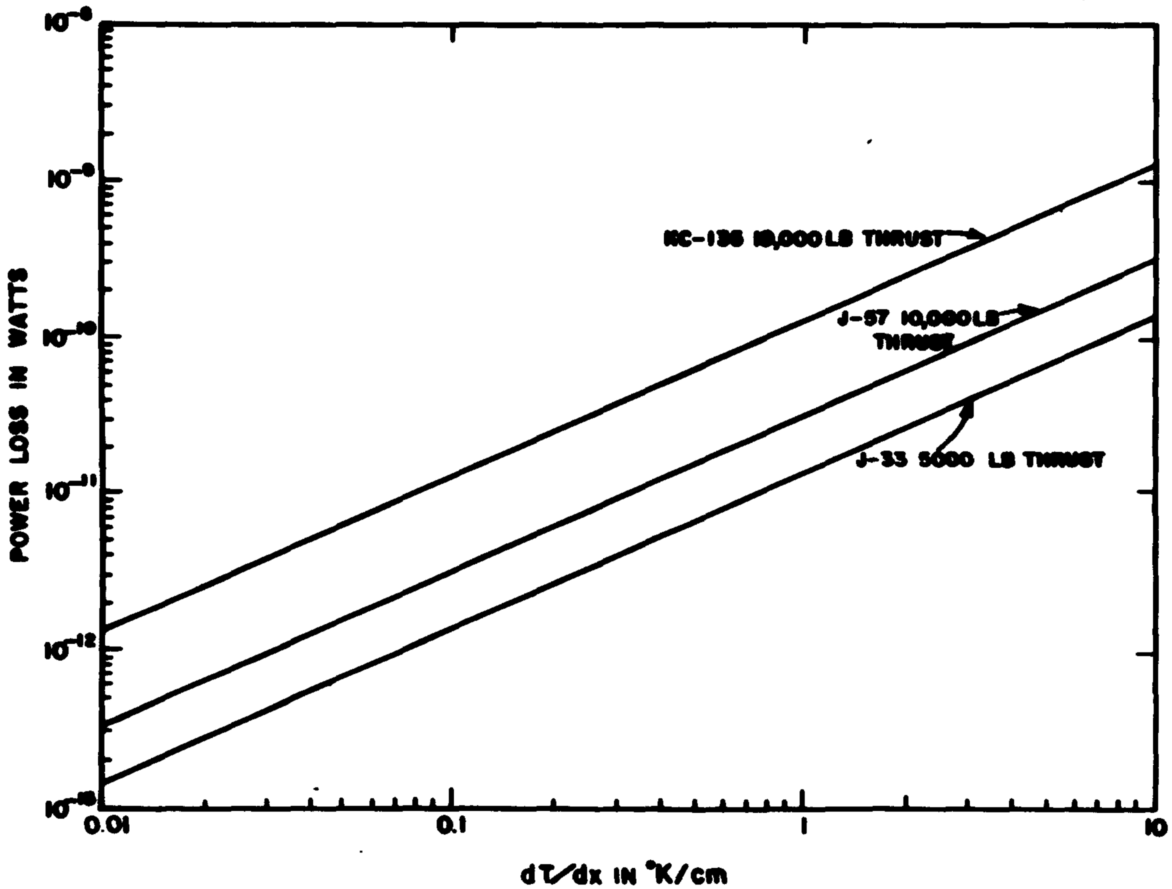

Figure 2. Power Loss vs Temperature Gradient for Selected Jet Engines

small that spin temperature and lattice temperature may be considered independently, what interaction there is between the two systems seems to bring them into equilibrium at the same temperature.

Second, equilibrium statistics are being applied to a system that most assuredly is not in equilibrium. Since the proper statistical representation is not known, the results are open to question.

Third, the resonance broadening of spin-spin interaction comes about because many of the nuclei have magnetic dipole moments, hence magnetic fields, associated with them. The effect of these magnetic fields is to place the nuclei, upon which the resonance phenomenon is dependent, in a very heterogeneous state: one nucleus 'feels' a magnetic field of a certain strength, while a neighbor 'feels' a different strength, and so on. Thus, a band of frequencies is produced instead of a single frequency. Normal resonance techniques could be applied to a sample in equilibrium and the extent of this effect determined to an order of magnitude, provided it is within the resolving power of the spectrometer. A theoretical approximation shows this effect to be negligible in the gas under consideration. (See Appendix B.)

A fourth factor is the homogeneity of the magnetic field in which the entire system is immersed. This need not be discussed further than to indicate that a change of 1 cps in the resonant frequency for protons is produced by a change in magnetic field of approximately 25 gamma (1 gamma $= 10^{-5}$ gauss). The same broadening effect as for spin-spin interaction would be noted.

Fifth, the radiation, if any, would be incoherent.

Sixth, no consideration is given to the time of relaxation from the higher to the lower energy state. It is assumed that the relaxation takes place at the same rate as the thermal relaxation $dT/dt = \bar{v}_x (dT/dx)$. This may not be the case.

2. Experimental Report and Results

Based on the preceding calculations, several attempts were made to detect nuclear magnetic resonance as supposedly produced in jet exhausts. The critical assumption was that the energy associated with the resonance phenomenon would be radiated.

Measurements were made under line-of-sight conditions from the Katahdin Hill field site of the Astrosurveillance Sciences Laboratory to the jet engine static test stand (approximately one-half mile away). The frequency of resonance could be only approximated and the bandwidth was unknown. For these

reasons, a sweep frequency technique was used in order not to lose any information nor to have long, noisy engine runs. Furthermore, the expected signal had a low intensity level, but the new electronic analog multiplier developed by the Electronic Development Section of the Astrosurveillance Sciences Laboratory afforded an extra gain characteristic in signal detection. A block diagram of the entire system is shown in Fig. 3 and an equipment list and specifications are found in Appendix C.

The process involved in the system was pseudo cross correlation:

Let $A \cos \omega t$ be the signal input from the sweep oscillator where for the moment $\omega \neq f(t)$ and A is never a function of time. Let $A_i \cos \omega_i t$ be the signal to be detected where, again for the moment, A_i and $\omega_i \neq f(t)$. The multiplier multiplies and integrates the two signals over a given time. The mathematics are:

(1) Multiplication

$$A \cos \omega t \; A_i \cos \omega_i t = AA_i \cos \omega t \; \cos \omega_i t$$

(2) Integration

$$A(T) = AA_i \int_0^T \cos \omega t \; \cos \omega_i t \, dt = AA_i \left[\frac{\sin(\omega - \omega_i)t}{2(\omega - \omega_i)} + \frac{\sin(\omega + \omega_i)t}{2(\omega + \omega_i)} \right]_0^T$$

$$= \frac{AA_i}{2} \left[\frac{\sin(\omega - \omega_i)T}{\omega - \omega_i} + \frac{\sin(\omega + \omega_i)T}{\omega + \omega_i} \right].$$

This result may be analyzed by saying that as $\omega \rightarrow \omega_i$ the first term goes to infinity. The second term is always very small in comparison and may be neglected. Therefore,

$$A(T) = \frac{AA_i \sin 2\pi (f - f_i) T}{2\pi (f - f_i)}$$

In the actual experiment the following parameters were used for a magnetic field strength of 0.56 gauss:

$f = f_o + k\tau$

f ranges from 2290 to 2560 cps as τ ranges from 0 to 30 sec

$f_o = 2290$ cps

$2560 = 2290 + 30k$

$f = 2290 + 9\tau$

$$A(\tau) = \left(\frac{AA_i}{2}\right) \frac{\sin 2\pi (2290 + 9\tau - f_i) \; T}{2\pi (2290 + 9\tau - f_i)}$$

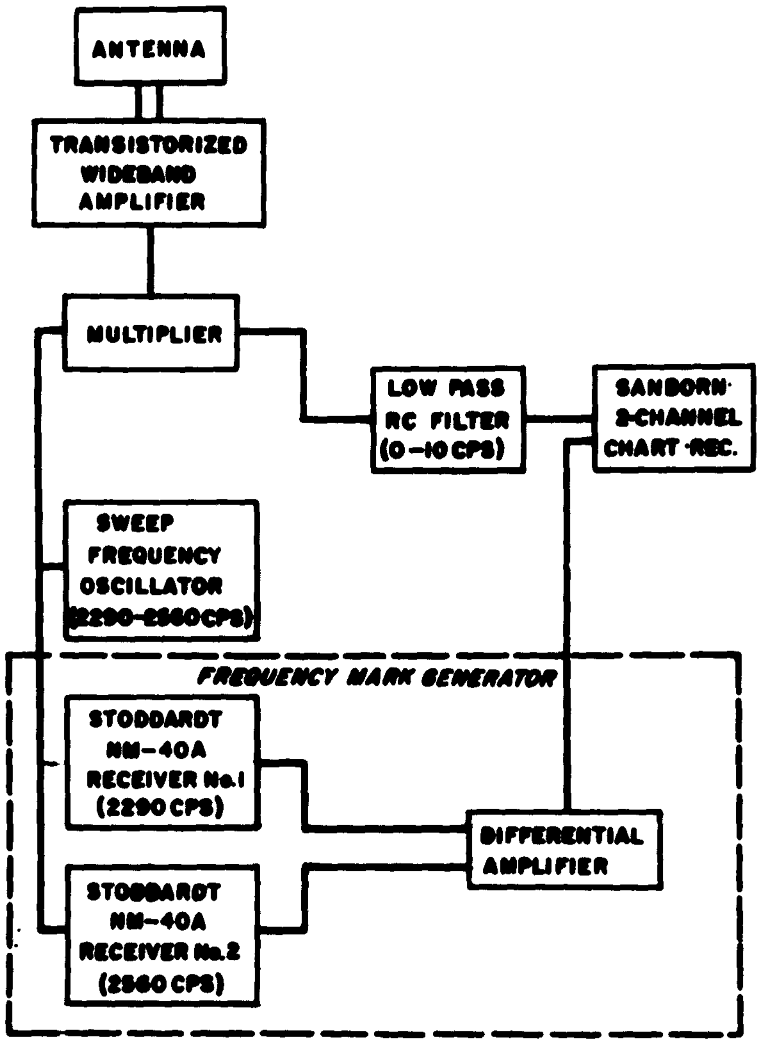

Figure 3. Detection System No. 1

As an example of the theoretical response, f_i = 2400 cps.

$$A(\tau) = \left(\frac{AA_i}{2}\right) \frac{\sin 2\pi(9\tau - 110)\ T}{2\pi(9\tau - 110)} = \left(\frac{AA_i}{4}\right) \frac{\sin 2\pi(9\tau - 110)\ T}{9\tau - 110} .$$

This response was filtered to pass only those frequencies below 10 cps. At that portion of the equation near f_i = 2400 cps covered by T ranging from 18 to 22 sec, the response would be that shown in Fig. 4. Figure 5 is a trace of an actual pickup by the system.

The disadvantage of this system was that the frequencies had to be read from a calibrated scale. This was tedious since the speed of the sweep-oscillator varied from one sweep to the next, requiring the construction of numerous scales. Furthermore, human judgment was needed in the case of small signal possibilities.

Data read off was recorded as a panoramic frequency plot showing number of occurrences vs frequency for times when the engine was in operation and times when it was not. Figures 6, 7, 8, and 9 show the results.

The only indications of possibly abnormal activity were on the KC-135 test. Two bands of activity were observed, one at about 2360 to 2365 cps and the other at about 2475 to 2485 cps. Previous noise measurements showed expected peaks at 2320, 2385, 2440, 2495 (weak), and 2560 cps. These noise measurements were verified because each of these frequencies, with the exception of 2495 cps, was usually detected. A further problem was that the nuclei could not be controlled so that radiation would occur in one of the observed quiet bands.

Attempts were made to study the amplitude of received signals from the characteristic of the system output. Trends were found that indicated the possibility of calibration by means of the central maximum deflection and to a lesser extent the width of the observed characteristic. The equipment would have needed greater refinement, however for more precise calibration.

The possibility of a high incidence of error in judgment made mandatory machine analysis of the data. The final tests were made with the system shown in Fig. 10. The operation of this system is simple. The received signal is amplified and fed into a mixer where it is beat against a local oscillator set at approximately the center frequency of the band of interest (2300 to 2550 cps). The difference is then passed by the low pass filter, amplified, and recorded at slow speed on magnetic tape. The tape playback is speeded up (in this case four times to fit the Vibralyzer range of 5 to 500 cps), fed into the Vibralyzer and subsequently analyzed. No peculiarities were noted, and the results were negative.

3. Conclusions

Although there is probably a resonance energy loss due to a change of nuclear magnetic energy state from the higher level to the lower level, it was not possible to detect the loss by means of radiation techniques. This may be attributable to the inhomogeneous conditions (magnetic field) under which the measurements were made. In only one case out of seven test runs was there the slightest possibility of detection of any sort of irregularity, and that occurred in two bands.

Under conditions of strictly controlled magnetic field and thermal gradient with a low noise background, the energy loss, if in the form of electromagnetic radiation, might be detected. In fact, experiments under highly controlled conditions should answer the several problems posed earlier.

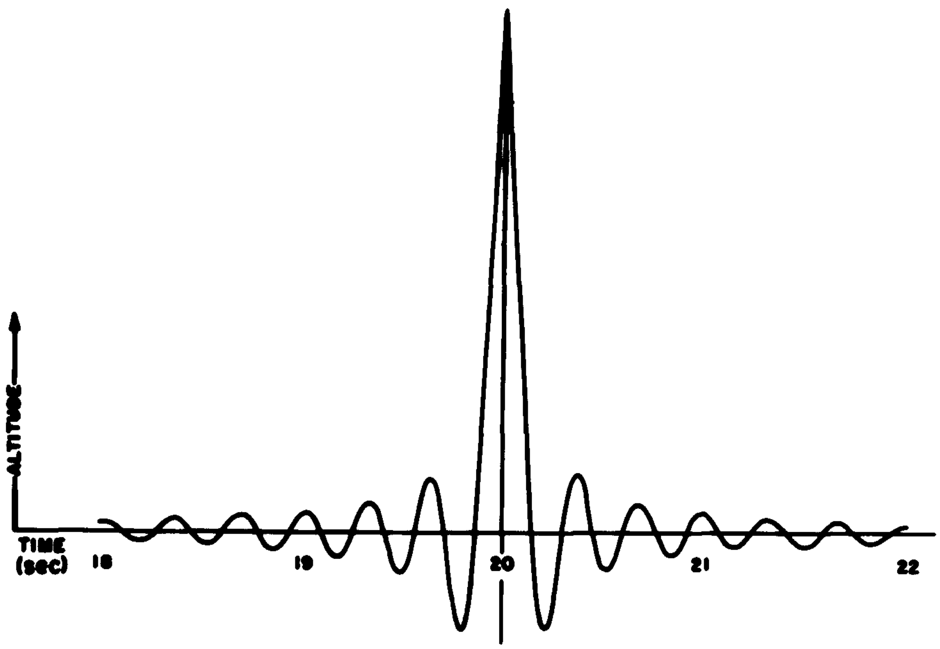

Figure 4. Theoretical System Output

Figure 5. Actual System Output for a Typical Sweep Showing Several of The Theoretical Characteristics

ENGINE TYPE: J-33

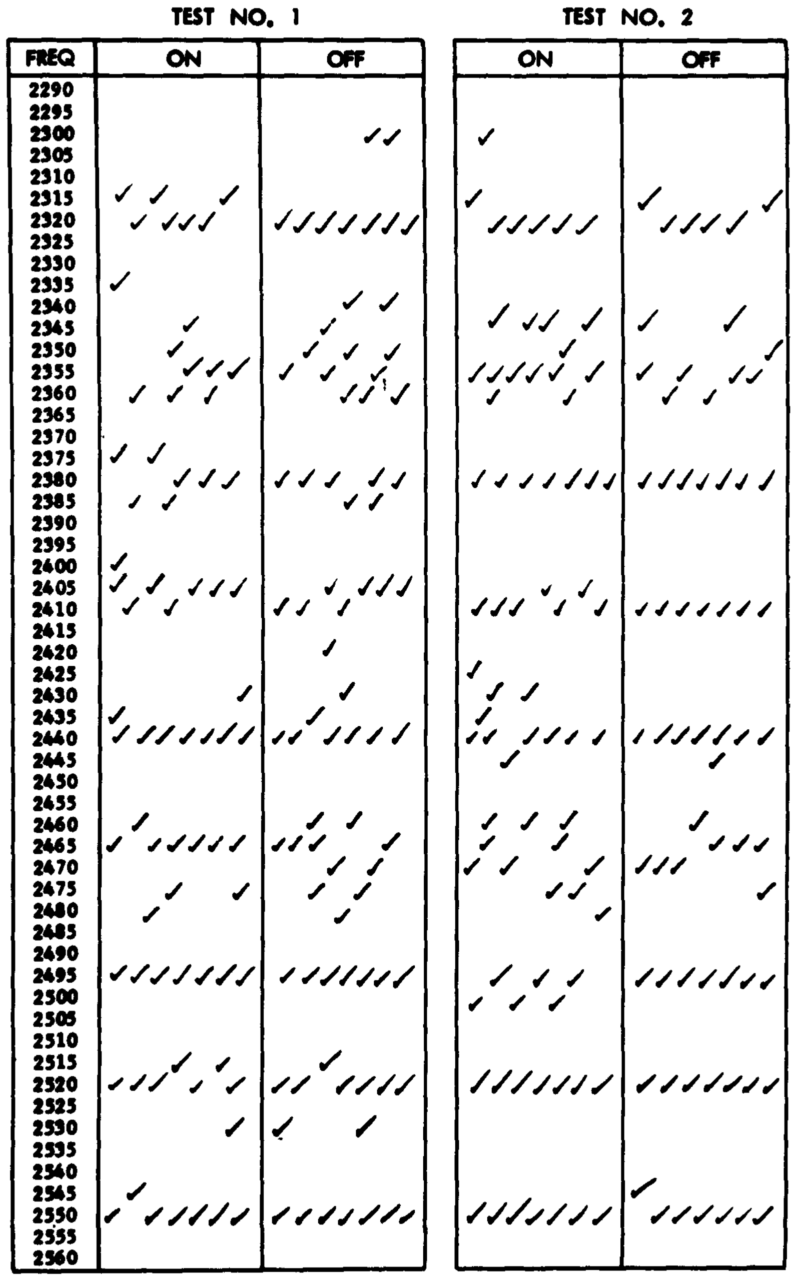

Figure 6. Number of Occurrences vs Frequency, 21 November 1960

ENGINE TYPE: J-33

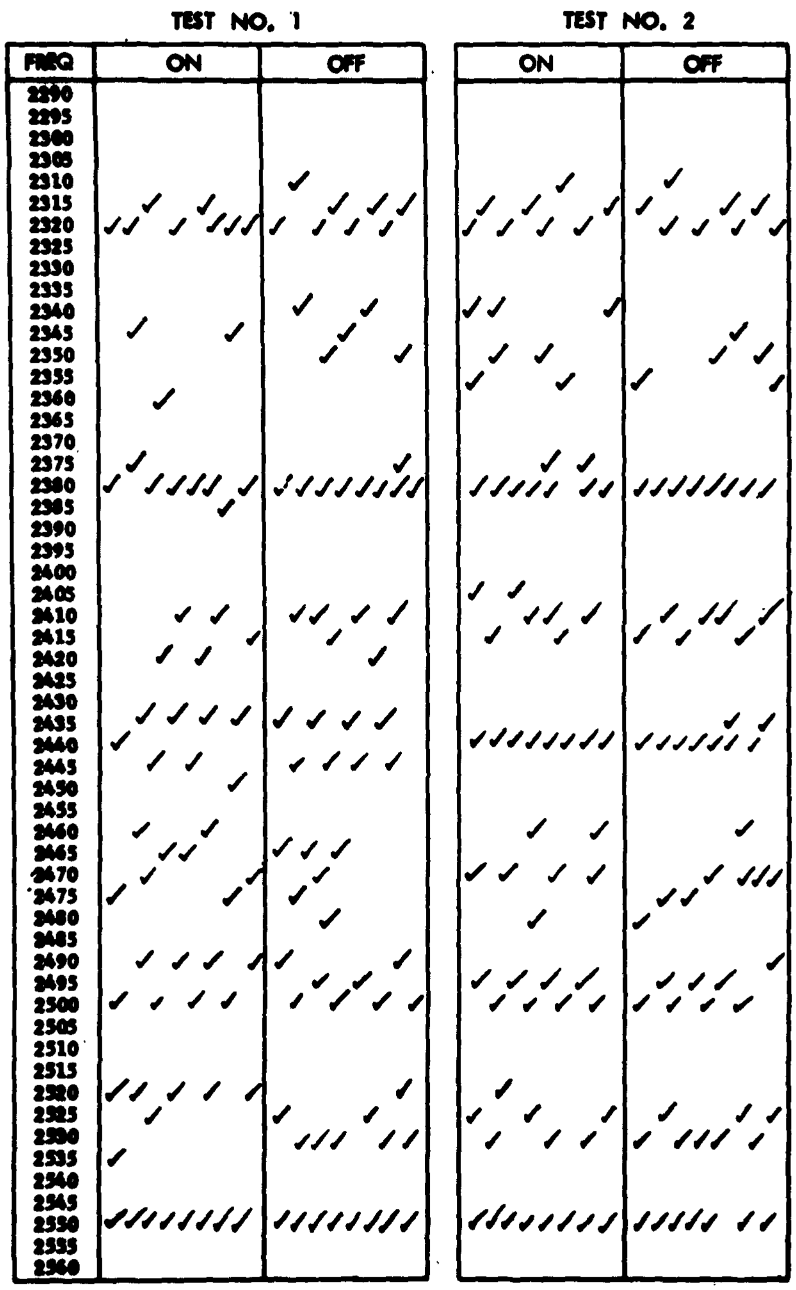

Figure 7. Number of Occurrences vs Frequency, 22 November 1960

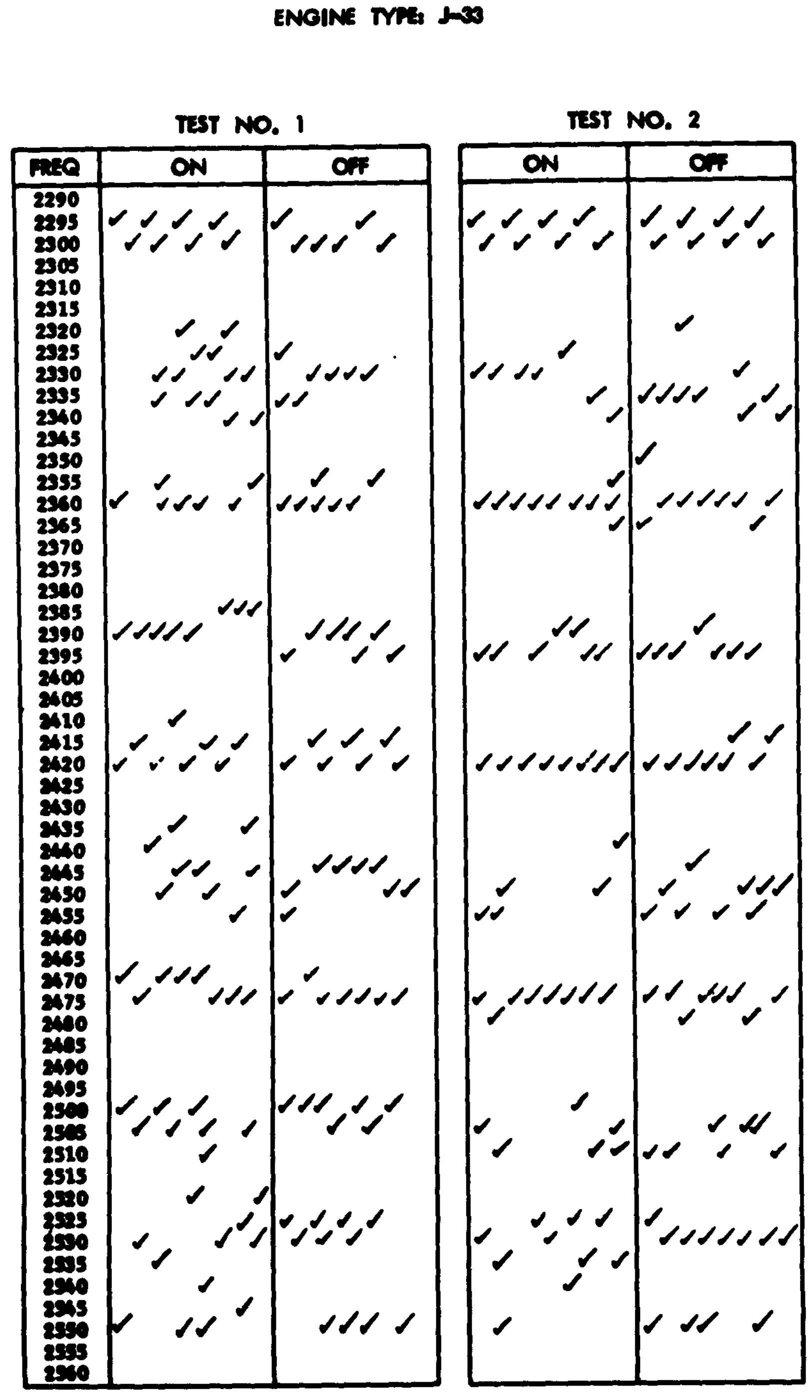

Figure 8. Number of Occurrences vs Frequency, 23 November 1960

ENGINE TYPE: KC-135 TAKEOFF

TEST NO. 1

FREQ	ON	OFF
2290		
2295		✓
2300	✓✓✓✓✓	✓✓✓✓✓
2305	✓	
2310		
2315		✓✓
2320	✓✓✓✓	✓
2325	✓✓	✓✓✓
2330	✓	✓
2335		
2340		
2345		
2350	✓	
2355		✓✓
2360	✓	
2365	✓✓	
2370	✓	
2375		
2380	✓	✓
2385	✓✓✓	✓✓✓
2390	✓✓✓	✓✓✓
2395		
2400		
2405	✓✓	
2410		
2415		
2420		✓
2425	✓✓✓✓✓✓✓	✓✓✓✓✓✓
2430		
2435		
2440		✓
2445	✓✓✓✓✓✓✓	✓✓✓✓✓
2450		✓✓
2455		
2460		
2465		
2470	✓✓	
2475		
2480	✓✓	✓✓
2485	✓✓	✓
2490		
2495		
2500	✓✓✓	✓✓
2505	✓✓✓✓	✓✓✓✓✓
2510		
2515		
2520		
2525		
2530	✓✓	
2535	✓	✓✓
2540	✓✓✓	✓✓✓
2545		✓✓
2550	✓✓✓✓	
2555		✓✓
2560	✓✓✓	✓✓✓✓

Figure 9. Number of Occurrences vs Frequency, 5 December 1960

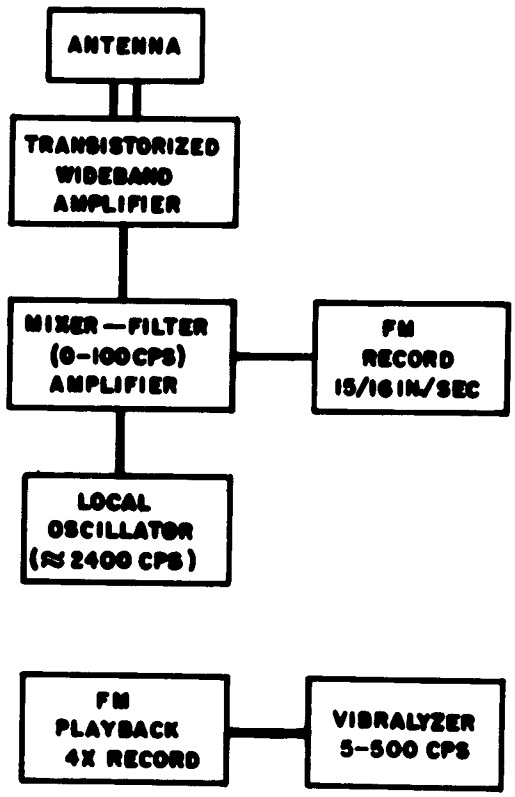

Figure 10. Detection System No. 2

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APPENDIX A

Jet Engine Characteristics

Engine type: J-33

Thrust: 5000 lb

Fuel type: JP-4

Hydrogen content of fuel: 13.6%

Fuel rate: 1.44 lb/sec

Proton rate: $\dfrac{\text{Fuel rate} \times \text{Hydrogen content of fuel}}{\text{Weight of a single hydrogen nucleus}} = N_o$

$$N_o = \frac{1.44\ \text{lb/sec} \times 453.6\ \text{gm/lb} \times 0.136}{1.67 \times 10^{-24}\ \text{gm/nucleus}} = 5.32 \times 10^{25}\ \text{proton/sec}$$

Exhaust temp: $T_E = 1240°F = 940°K$

Ambient temp: $T_A = 300°K$

Exhaust velocity (axial) :

$$v_E = \frac{\text{Thrust} \times \text{acceleration of gravity}}{\text{Fuel rate}}$$

$$= \frac{5000\ \text{lb} \times 32.2\ \text{ft/sec}^2}{1.44\ \text{lb/sec}} = 11.1 \times 10^4\ \text{ft/sec} = 338 \times 10^4\ \text{cm/sec}$$

Ambient velocity: $v_A = 4.58 \times 10^4$ cm/sec

Proton gyromagnetic ratio: $\gamma_I = 2.675 \times 10^4$/sec/gauss

Population shift:

$$\frac{dN}{dt} = \left(\frac{(5.32 \times 10^{25})}{4}\right)$$

$$\frac{(2.675 \times 10^4/\text{sec/gauss})(1.05 \times 10^{-27}\text{erg/sec})(0.56\ \text{gauss})(167 \times 10^4\text{cm/sec})}{(1.38 \times 10^{-16}\text{erg/deg})\ (940 \times 300\ \text{deg}^2)} \left(\frac{dT}{dx}\right)$$

$$\frac{dN}{dt} = 8.97 \times 10^{18} \left(\frac{dT}{dx}\right)/\ \text{sec}$$

Energy/shift: $h\nu = 1.57 \times 10^{-23}$ ergs

Power loss: $P = 1.42 \times 10^{-11} \left(\frac{dT}{dx}\right)$ watts

Engine type: J-57

Thrust: 10,000 lb

Fuel type: JP-4

Hydrogen content of fuel: 13.6%

Fuel rate: 3.6 lb/sec

Proton rate:

$$N_o = \frac{3.6 \text{ lb/sec} \times 453 \text{ gm/lb} \times 0.136}{1.67 \times 10^{-24} \text{ gm/nucleus}} = 1.33 \times 10^{26} \text{ proton/sec}$$

Exhaust temp: $T_E = 1000°F = 813°K$

Ambient temp: $T_A = 300°K$

Exhaust velocity (axial):

$$v_E = \frac{10,000 \text{ lb} \times 32.2 \text{ ft/sec}^2}{3.6 \text{ lb/sec}} = 8.9 \times 10^4 \text{ft/sec} = 274 \times 10^4 \text{cm/sec}$$

Ambient velocity: $v_A = 4.58 \times 10^4$ cm/sec

Proton gyromagnetic ratio: $\gamma_I = 2.675 \times 10^4$/sec/gauss

Population shift:

$$\frac{dN}{dt} \left(\frac{(1.33 \times 10^{26})}{4}\right) \frac{(2.675 \times 10^4)(1.05 \times 10^{-27})(0.56)(135 \times 10^4)}{(1.38 \times 10^{-16})(813 \times 300)} \left(\frac{dT}{dx}\right)$$

$$\frac{dN}{dt} = 2.10 \times 10^{19} \left(\frac{dT}{dx}\right)/\text{sec}$$

Energy/shift: $h\nu = 1.57 \times 10^{-23}$ ergs

Power loss: $P = 3.30 \times 10^{-11} \left(\frac{dT}{dx}\right)$ watts

Engine type: Four J-57's (KC-135)

Characteristics all 4X J-57's

Power loss KC-135: $P = 1.32 \times 10^{-10} \left(\frac{dT}{dx}\right)$ watts

APPENDIX B

A theoretical approximation of the spin-spin interaction is as follows:

Assume the ideal engine in which the exhaust pressure equals the ambient pressure. The mean free path in the exhaust, based on hard sphere considerations and a Maxwellian velocity distribution, is

$$\lambda = \frac{KT}{\sqrt{2}\, p\pi d^2}$$

where p is the pressure and d is the diameter of the molecules. Combustion products are principally CO_2 and H_2O. Taking, then, the length of the CO_2 bond as d,

$$d = 1.42 \times 10^{-8} \text{cm}$$

$$d^2 = 2.02 \times 10^{-16} \text{cm}^2$$

$$p = 1.01 \times 10^{6} \text{dynes/cm}^2$$

$$T = 1000°F = 813°K$$

$$\lambda = \frac{(1.38\times10^{-16} \text{dyne cm/deg})(813 \text{ deg})}{(1.414)(1.01\times10^{6} \text{dyne/cm}^2)(3.14)(2.02\times10^{-16} \text{cm}^2}$$

$$\lambda = 1.24 \times 10^{-5} \text{cm}$$

The local field produced by a nucleus having the magnetic moment of a proton

$$\mu_p = 1.41 \times 10^{-23} \text{erg/gauss}$$

is given as

$$H_{local} \approx \frac{\mu_p}{r^3} \approx \frac{1.41 \times 10^{-23}}{(1.24\times10^{-5})^3} \approx 7.34 \times 10^{-7} \text{ gauss}$$

The local field is negligible.

APPENDIX C

System Characteristics

System No. 1

Antenna

3 ft by 4 ft, 274 turns, No. 18 wire

Bandwidth at 2400 cps ≈ 200 cps

Transistorized amplifier

Gain: 50,000

Bandpass: 500 cps to 6 kcps

Flat from 1.5 kcps to 3 kcps

Equivalent rms input noise ≈ 0.5 μv

Saturation ≈ 30 μv

Multiplier

See Frederick Slack, Electronic Analog Multiplier, AFCRL 541, July 1961

Recorder

Sanborn Twin-Viso Model 60-1300

Sweep frequency oscillator

Modified General Radio Type 1304B

Receivers

Stoddardt NM-40A Radio Interference Field Intensity Meter

System No. 2

FM Recorder

Ampex FR-100A

Vibralyzer

Kay Lab "Vibralyzer"

UNCLASSIFIED

AF Cambridge Research Laboratories, Bedford, Mass. Electronics Research Directorate
NUCLEAR MAGNETIC RESONANCE IN FLAMES, by Darrell R. Parnell, 1/Lt, USAF. February 1962. 22 pp incl. illus. AFCRL-62-51
Unclassified report

In the thermal generation of nuclear magnetic resonance phenomena, such as is found in flames or hot exhausts, energy is lost during the transition from a higher- to a lower-energy nuclear magnetic quantum state. The interaction that takes place is explained in simple theoretical terms, and the effects of resonance broadening by spin-spin interaction and an inhomogeneous magnetic field are considered. The amount of energy lost during the cooling of a hot jet exhaust was calculated using the environmental magnetic field of the earth. On the assumption that the energy was radiated by means of electromagnetic waves, attempts were made to detect this energy loss.

1. Nuclear Resonance
2. Jet Exhaust Flames
3. Instrumentation—Physics laboratory equipment

I. Parnell, D. R.

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